05 APR 2002

FORM PTO-1390 (Modified) (REV 11-98) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**	ATTORNEY'S DOCKET NUMBER **070[redacted]03U1** U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/089999

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/AU00/01053	**5 September 2000**	**12 October 1999**

TITLE OF INVENTION

VEHICLE WEIGH-IN-MOTION METHOD AND SYSTEM

APPLICANT(S) FOR DO/EO/US

TAPANES et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☒ Certificate of Mailing by Express Mail — Express Mail No. EL403199051US
20. ☒ Other items or information:

Return Postcard

PCTUS1/REV03

JC15 Rec'd PCT/PTO 05 APR 2002

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/089959	INTERNATIONAL APPLICATION NO. PCT/AU00/01053	ATTORNEY'S DOCKET NUMBER 07082.0003U1

21. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS	PTO USE ONLY
☒ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO and International Search Report not prepared by the EPO or JPO	$1,000.00		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but Internation Search Report prepared by the EPO or JPO	$860.00		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	$710.00		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4)	$690.00		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4)	$100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =		$1,040.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		$0.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	28 - 20 =	8	x $18.00	$144.00	
Independent claims	4 - 3 =	1	x $84.00	$84.00	
Multiple Dependent Claims **(check if applicable).**			☐	$0.00	
TOTAL OF ABOVE CALCULATIONS			=	$1,268.00	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).**			☒	$634.00	
SUBTOTAL			=	$634.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).			+	$0.00	
TOTAL NATIONAL FEE			=	$634.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**			☐	$0.00	
TOTAL FEES ENCLOSED			=	$634.00	
				Amount to be: refunded	$
				charged	$

☒ Credit Card Payment Form PTO-2038 authorizing payment in the amount of $634.00

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **14-0629** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Sumner C. Rosenberg
NEEDLE & ROSENBERG, P.C.
Suite 1200 The Candler Building
127 Peachtree Street, N.E.
Atlanta, GA 30303-1811

SIGNATURE

Sumner C. Rosenberg
NAME

28,753
REGISTRATION NUMBER

April 5, 2002
DATE

10/089999

JC15 Rec'd PCT/PTO 05 APR 2002

ATTORNEY DOCKET NO. 07082.0003U1
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	)	
TAPANES *et al.*	)	
Serial No. Unassigned	)	Group Art Unit: Unassigned
Filed: Concurrently Herewith	)	Examiner: Unassigned
FOR: "VEHICLE WEIGH-IN-MOTION METHOD AND SYSTEM"	)	

10089999.040502

PRELIMINARY AMENDMENT

Commissioner for Patents
Box PCT (IPEA/AU)
Washington, D.C. 20231

NEEDLE & ROSENBERG, P.C.
Suite 1200, The Candler Building
127 Peachtree Street, N.E.
Atlanta, Georgia 30303-1811

April 5, 2002

Sir:

Prior to the issuance of an Office Action pertaining to the above-identified patent application, please enter the following preliminary amendment and consider the following remarks. A copy of the marked-up claims is attached as Appendix A to this Amendment.

IN THE CLAIMS

Please rewrite the following claims:

9. (Amended) The station of claim 1 further including an axle detector for detecting the presence of axles of a vehicle so that an indication of the number of axles of the vehicle can be determined.

21. (Amended) The station of claim 1 wherein the load sensing device is located between 500 and 1000 mm below the surface of the roadway.

IN THE SPECIFICATION

On page 1 of the specification, before the first paragraph, please insert the following:

-- The present application is a 35 U.S.C. § 371 national phase application from, and claims priority to, international application PCT/AU00/01053, filed September 5, 2000 (published under PCT Article 21(2) in English), which claims priority to Australian patent application No. PQ3357, filed October 12, 1999, which applications are hereby incorporated herein in their entirety.--

REMARKS

Claims 9 and 21 have been amended herein to remove the multiple dependencies. This amendment neither narrows the scope of the claims nor was it made for reasons related to patentability.

The specification is amended herein to update the priority claim for this application. It is believed that no new matter has been added by this amendment, and applicants respectfully request entry of same into the present application.

No fee is believed due; however, the Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. 14-0629.

Respectfully submitted,

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CERTIFICATE OF EXPRESS MAILING

I hereby certify that this correspondence along with anything indicated as being attached or included is being deposited with the United States Postal Service as Express Mail No. EL403199051US in an envelope addressed to: Commissioner for Patents, Box PCT (IPEA/AU), Washington, D.C. 20231, on the date shown below.

David Thorpe

4-5-02
Date

Appendix A
Marked-up claims

9. (Amended) The station of [anyone of claims] claim 1 [to 7] further including an axle detector for detecting the presence of axles of a vehicle so that an indication of the number of axles of the vehicle can be determined.

21. (Amended) The station of [anyone of claims] claim 1 [to 20] wherein the load sensing device is located between 500 and 1000 mm below the surface of the roadway.

VEHICLE WEIGH-IN-MOTION METHOD AND SYSTEM

FIELD OF THE INVENTION

This invention relates to a method and systems formed for weighing vehicles in motion. The methodology and systems disclosed offer a radically different approach to the problem of monitoring vehicle weigh-in-motion (WIM) by allowing continuous in-road monitoring, thus revolutionising WIM systems for pavement monitoring and enforcement applications.

ART BACKGROUND

The pressure on existing road systems throughout developed countries is increasing. In particular, the loads which heavy vehicles impose on pavements and bridges have a direct and disproportionate bearing on the rate of wear and the life of the infrastructure and, therefore, on the associated maintenance, refurbishment and replacement costs. Road transport managers require a vehicle data system to provide information that will enable them to manage the road transport network in the most economical and efficient manner. One such piece of required vehicle information is mass. As the demand for better roads has increased and as the emphasis has turned from new construction to actual conservation, there have been considerable technical developments to produce more efficient and accurate vehicle mass collection mechanisms, namely, weigh-in-motion (WIM).

In recent years, government and private industry have been giving considerable attention to the development of practical and effective methods for instrumenting infrastructure in order to monitor traffic conditions,

enforce load restrictions and determine the state of health of the infrastructure. Vehicle WIM monitoring systems, capable of automatically and accurately measuring the configuration, speed and weight of moving vehicles, continue to play a major role in this endeavour. However, current WIM techniques in use worldwide possess a number of limitations.

The basic principles of WIM technology were developed in the 1950s. However, adequate instrumentation, data processing and storage and suitable weight sensors were non-existent or at best crude. Solid-state electronics and digital computers came into practicable use in the 1960s. Weight sensor development also continued.

Commercial WIM devices currently in use throughout the world include:

1. Plates or beams instrumented with strain gauges, load cells or capacitive strips.
2. Culverts and bridges instrumented with strain gauges.
3. Piezo-electric strips.

All of these methods have one or more disadvantages including varying degrees of accuracy, cost, installation difficulties, and reliability. It is arguable that, to date, no system has been able to reliably and consistently weigh random vehicles at highway speeds to enforcement accuracy (within ±5% of gross vehicle mass, 95% of the time).

In Australia, in the late 1960's and early 1970's numerous methods of weighing vehicles at low and high speeds were proposed. One of the systems consisted of a steel plate supported along two of its edges and mounted flush with

the road surface. The system electronically measured the resulting strain produced.

As a production tool, the first WIM system to appear in Australia was the Low Speed Electronic Mass Unit (LSEMU) which comprised a plate supported by four load cells.

In 1978 investigation into the application of the system to high speed weighing took place. This culminated in the High Speed Electronic Mass Unit (HSEMU).

Australia has also pioneered the use of strain gauge weight sensor systems. A bridge based strain gauge system called AXWAY has been developed. Experience with the AXWAY system led to the development of the CULWAY system. With CULWAY, strain gauges were mounted onto a culvert rather than a bridge.

To date, several highly successful vehicle WIM systems capable of measuring the configuration, speed and weight of moving vehicles have been developed. These systems play a major role in providing the feedback required to extend the lifetimes of existing road systems and infrastructure. Australian use of WIM can be characterised into a number of uses and applications, as follow:

1. infrastructure design and management;
2. freight/trade planning and regulation; and
3. enforcement and detection.

Investigations have been made into a number of potential advances and totally new high-speed weight sensor types, as follow:

1. concrete culverts - different version of CULWAY;
2. strain gauged plates;
3. piezo-electric cables;
4. hydraulic tubes - consisting of a pneumatic tube filled with an incompressible fluid and embedded in a rubber pad; and
5. capacitive strips.

These new weight sensors have demonstrated promising results in the laboratory. However, during actual field tests, the results have not been satisfactory.

Engineered structures are usually not monitored in real-time due to the difficulties in connecting conventional sensors to them and because of the limitations of the sensors. This is particularly so when dealing with pavements. In the case of detecting and measuring moving vehicle weights on roads, an accurate, cost-effective and in-road sensing system is not readily available; commercially available equipment suffers from a number of limiting problems. Either temporary, surface mounted sensors on roads or instrumented culverts are used to perform a reasonably accurate, but non-enforceable, estimate of vehicle weights. Accurate, enforcement quality (within 5%) measurements are generally limited to low-speed or stationary measurements at specially made and relatively costly static weigh stations. Furthermore, with conventional weigh stations, drivers are inconvenienced and station staff spend most of their time checking the vast majority of vehicles that conform, thus it is a very time consuming and costly exercise. The combination of the HSEMU and LSEMU, overcomes some of these problems. The HSEMU, which measures the weight of vehicles travelling at highway speeds, but to a non-enforceable accuracy, provides an initial screening, so

that only non-conforming vehicles proceed to the enforcement accuracy LSEMU. On the other hand, a load sensor incorporated within the road itself which continuously and accurately monitors moving vehicle weights in real-time should provide significant cost, time and asset savings. To date, however, effective, enforcement quality, real-time weigh-in-motion systems that can be embedded in the roads are not commercially available.

Fibre optic sensors offer a radically different approach to this problem and could allow continuous, in-road WIM monitoring, thus revolutionising WIM systems for pavement monitoring and enforcement applications. This is possible because optical fibres can be more than mere signal carriers. Light that is launched into and confined to the fibre core propagates along the length of the fibre unperturbed unless acted upon by an external influence. Specialised sensing instrumentation may be configured such that any disturbance of the fibre which alters some of the characteristics of the guided light (ie., amplitude, phase, wavelength, polarisation, modal distribution and time-of-flight) can be monitored, and related to the magnitude of the disturbing influence. Such modulation of the light makes possible the measurement of a wide range of events and conditions, including:

1. Strain
2. displacement
3. vibration/frequency
4. acoustic emission
5. temperature
6. load

Fibre optic sensor technology has progressed at a rapid pace over the last decade. Different configurations of fibre sensing devices have been developed for monitoring specific parameters, each differing by the principle of light modulation. Fibre optic sensors may be intrinsic or extrinsic, depending on whether the fibre is the sensing element or the information carrier, respectively. They are designated "point" sensors when the sensing gauge length is localised to discrete regions. If the sensor is capable of sensing a measurand field continuously over its entire length, it is known as a "distributed" sensor; "quasi-distributed" sensors utilise point sensors at various locations along the fibre length. Fibre optic sensors can be transmissive or can be used in a reflective configuration by mirroring the fibre end-face.

Hence, fibre optic sensors are actually a class of sensing device. They are not limited to a single configuration and operation unlike many conventional sensors such as electrical strain gauges and piezo-electric transducers. Consequently, fibres are now replacing the role of conventional electrical devices in sensing applications to the extent where we are now seeing a multitude of sensing techniques and applications being explored for practical gain.

The advantages of fibre optic technology for WIM applications lie in its speed, security, safety, sensitivity and robustness, as well as its immunity to corrosion and electromagnetic interference. Additionally, these devices provide several operational advantages for WIM systems over existing technologies, such as in-situ (embedded in the pavement) sensing, real-time measurement, on-line analysis, simultaneous, distributed sampling, component miniaturisation and opportunity for feedback control.

Consequently, fibre optic sensors potentially offer the WIM industry lower cost products with enhanced capabilities. Installing the sensors directly into the pavement offers the ability to reduce vehicle-to-sensor, impact-related sensor response inconsistencies, and will result in significant installation and infrastructure cost savings and the potential for automated enforcement techniques. Consequently, the decreasing cost, inherent properties and operational advantages of fibre optic sensing technologies are anticipated to significantly reduce the cost and complexity of future WIM monitoring systems.

As a result, considerable research has been underway over the past decade into the development of fibre optic WIM systems. Previous research in this area involved the use of the following fibre optic sensing techniques:

1. Modalmetric multimode and microbending techniques: Although this type of sensor is very sensitive, the modulation of the modal pattern is generally non-linearly related to all disturbances, resulting in deep fading and drifting of the output signal. This behaviour limits the use of this sensor for quantitative strain measurements, but nonetheless it can be used as a threshold-type sensor. Modalmetric sensors are capable of sensing many parameters, however, their sensitivities are generally lower than interferometric sensors and localisation of the sensing region is difficult (resulting in sensitive leads). However, for WIM applications the modalmetric sensors offer the advantage of detecting disturbances over long lengths of fibre (they are generally a distributed sensor).

A major problem experienced with the prior art results using this sensor to date is that almost all the work has been based on a surface-mounted pad or elevated platform, creating significant impact-related sensor response inconsistencies or requiring the vehicle to approach at a very low speed. None of the prior art techniques used sensors embedded in the road.

2. Interferometric techniques:

Interferometric fibre optic sensors are a large class of extremely sensitive fibre optic sensors. Fibre optic interferometers are analogous to their respective classic bulk optic interferometers. Fibre optic interferometers are generally intrinsic sensors in which light from a coherent source is equally divided to follow two (or more) fibre-guided paths. The beams are then recombined to mix coherently and form a "fringe pattern" which is directly related to the optical phase difference experienced between the different optical beams. This sensing technique is based primarily on detecting the optical phase change induced in the radiation field as it propagates along the optical fibre.

They are typically used when ultra-high sensitivities are required and/or in applications of localised measurements (ie., point sensing), although sensor lengths longer than one metre are sometimes possible. Singlemode fibre and associated components are used because they maintain the required spatial coherence of the light beam, whereas multimode fibres do not. The ultimate sensitivity and resolution of interferometers are limited by the effectiveness of the phase demodulation signal processing techniques used to interrogate the sensors. Although this class of sensor offers very high sensitivity, it has been largely

restricted to point sensing, due to the requirement for a long coherence length light source, thereby limiting its usefulness for WIM applications.

3. Polarimetric techniques:

Polarimetric fibre optic sensors are an attractive alternative to interferometric sensors when ultra-high sensitivity is not required, and longer sensor gauge lengths are desired. The polarimetric fibre optic sensor is capable of detecting many parameters with the advantage of being configured as a point sensor or distributed. Significant drawbacks of this sensor include the high cost of components and the complexity of the system (polarisation control, maintaining and monitoring components are required). The development of an accurate and reliable polarimetric system is further complicated by an inherent large sensitivity to temperature compared to strain (~40:1).

A major problem with the prior art results using this sensor to date is that almost all the work has been based on a surface-mounted pad or platform, creating significant impact-related sensor response inconsistencies or requiring the vehicle to approach at a very low speed. None of the prior art techniques used sensors embedded in the road.

4. Linear Modalmetric Interferometer:

In the first two years of their collaborative R&D project, the applicants of this provisional specification experimented with the use of a novel linear modalmetric interferometer inserted into saw-cuts on the surface of pavements. This sensing technique is based on the modulation of the modal distribution (effectively changing the intensity) in a multimode

optical fibre by external disturbances. This technique overcomes the inherent weaknesses of most multimode fibre optic sensors, offering truly localised, mechanically stable and linear sensing. In this method, the sensor response is a direct function of the disturbance on the sensitised portion of the fibre, regardless of where the disturbance occurs along the length. The disturbance may be in the form of physical movement (ie., compression (radially or axially), elongation, twisting, vibration, etc.) or microphonic effects (ie., travelling stress waves or acoustic emissions). This sensor had a further advantage over other modalmetric sensors in that it can operate as a single-ended device by mirroring the fibre end-face. Unfortunately, this sensor and the surface saw-cut installation technique were found to suffer from various problems, rendering it unsuitable.

Owing to the inherent problems and inconsistencies reported and experienced none of these detailed techniques, are considered to be practical for WIM applications. This observation is particularly justified when considering that research in this field has been underway for more than ten years and there is not yet a commercially available product.

BRIEF SUMMARY OF THE INVENTION

The object of the present invention is to provide a method and systems formed for weighing vehicles in motion.

The invention in a first aspect may be said to reside a weigh station for a vehicle in motion on a roadway, including;

a load sensing device located beneath the surface of the roadway for measuring the load of a vehicle in motion travelling on the roadway above the device; and

processing means for receiving a signal from the load sensing device and for providing an indication of the weight of the vehicle.

The invention may also be said to reside in a method of forming a weigh station for vehicles, including the steps of;

locating a load sensing device beneath the surface of the roadway;

coupling the load sensing device to a processor for receiving signals from the load sensing device and for enabling those signals to be processed to provide an indication of the weight of a vehicle travelling on the roadway above the load sensing device.

By locating the load sensing device beneath the roadway rather than at the surface of the roadway such as in or on the asphalt, the load sensing device is not subject to variations in the nature of the asphalt which may be caused by degradation of the asphalt due to normal wear, or change in the nature of the asphalt due to climatic conditions such as extreme heat or cold. These changes alter significantly the characteristic of the asphalt of the road surface and if the load measuring device is positioned in the asphalt or on the asphalt the changes of the asphalt layer influence the nature of the measuring device and therefore the accuracy of that device. By locating the device beneath the roadway the change of characteristic of the asphalt layer depending on weather conditions and also on usual wear, has no, or little, influence on the manner in which the sensing device performs. Thus, according to the invention the roadway

itself forms the weigh bridge and it is not necessary to construct an additional structure such as a concrete structure or culvert upon which the vehicle is required to travel (and usually park) in order to provide a weight measurement for the vehicle.

Preferably the step of locating the sensing device beneath the roadway comprises boring a hole beneath the roadway and locating the load sensing device within the bored hole.

In another embodiment of the invention the step of locating the sensing device beneath the roadway comprises digging a trench across the roadway, locating the load sensing device within the trench and filling the trench and restoring the roadway above the load sensing device.

Preferably the load sensing device is located on a substrate member, the substrate member being of sufficient length to extend substantially entirely across the width of at least one lane of the roadway.

Preferably the substrate member comprises an extrusion.

In one embodiment the extrusion comprises a U-shaped channel.

In another embodiment of the invention the extrusion comprises a flat beam located within a hollow conduit.

In one embodiment of the invention the load sensing device comprises a plurality of electrical strain gauges supported by the substrate member.

In another embodiment of the invention the load sensing device comprises an optical fibre supported by the substrate member.

Preferably, in the case of an optical fibre, the optical fibre is looped on the substrate member so that a plurality of runs of the optical fibre extend across substantially the entire width of at least one lane of the roadway.

In one preferred embodiment of the invention the system also includes an axle detector for detecting the presence of axles of a vehicle so that indication of the number of axles of the vehicle can be determined.

In one embodiment the axle detector is arranged on the surface of the roadway and extends across substantially the entire width of at least one lane of the roadway.

In another embodiment of the inventions the axle detector is arranged on the substrate member with together the load sensing device.

Preferably the bore in which the load sensing device is located is filled with a filler material after location of the load sensing device within the bore.

Preferably the step of forming the bore hole beneath the roadway comprises the step of forming an entry ditch or trench beside the roadway to enable access of a boring device for boring the borehole beneath the roadway.

Preferably the entry ditch or trench is restored to original form to render invisible the weighing station beneath the roadway.

Preferably the load sensing device includes a sensing fibre which extends substantially across the width of at least one lane of the roadway, a reference fibre, a coupler for coupling the sensing fibre and reference fibre, fibre sensor leads connected to the coupler, one of the fibre sensor leads being connected to a light source and the other fibre sensor lead being connected to a detector.

In other embodiments a third fibre sensor lead is connected to the coupler, the third fibre lead being connected to a second detector so that an indication of the weight of a vehicle can be obtained by the detectors based on phased demodulation.

In one embodiment the axle detector comprises a piezo-electric strip.

In another embodiment of the invention the axle detector comprises a fibre optic linear modelmetric interferometer comprising a multi-mode fibre connected to a single mode fibre patch chord, the patch chord being coupled to axle detector processing means for detecting a change in property of light in the multi-mode fibre in response to a

change in the load or strain experienced by the multi-mode fibre.

In one embodiment a light source is provided in the detector for launching light into the patch chord and multi-mode fibre.

In one embodiment the multi-mode fibre may have a mirrored end for reflecting light from the mirrored end back through the fibre so that the detector and light source are arranged at one end of the multi-mode fibre and patch chord.

In another embodiment the light source may be arranged at one end of the patch chord and multi-mode fibre, and the detector at the other end of the multi-mode fibre.

In another embodiment of the invention the load sensing device includes a single-mode sensing fibre including a Bragg grating, the single-mode fibre being connected to a single-mode fibre lead which is coupled to a coupler, the coupler having one arm connected to a light source and a further arm connected to a detector.

The invention may also be said to reside in a load sensing device for a weigh station which measures the weight of a vehicle whilst the vehicle is in motion on a roadway, the load sensing device including;

a substrate member; and

an optical fibre supported on the substrate member, the substrate member and optical fibre being of sufficient length to extend substantially across the entire width of at least one lane of a roadway.

Preferably the device is connected to a processor which includes a light source and a detector, the light source being for launching light into the fibre and the detector being for detecting light from the fibre, the processor processing signals from the detector to determine from a change in the characteristic of the signals, the weight of a vehicle travelling over the sensor.

In one embodiment a single run of the fibre is arranged on the substrate member.

In another embodiment the fibre may be looped on the substrate member so that a plurality of runs of the fibre extend along the length of the substrate member.

In one embodiment the substrate member comprises a generally U-shaped channel member having a base and two side walls, the fibre being supported on the base of the U-shaped channel member.

In another embodiment of the invention the substrate member comprises a beam arranged within a hollow conduit, the fibre being arranged on the beam.

Preferably the U-shaped channel or the beam and conduit are formed by extrusion.

In one preferred form the weigh station includes a:

load sensing device specially configured in the form of a sensing extrusion instrumented with a multiplicity of conventional electrical strain gauges or a suitable number

of other advanced sensing devices, such as fibre optic sensors, as the strain/load sensing units;

installation of the load sensing device, which operates across a partial or an entire lane of interest, in a borehole relatively deep under the pavement surface. Therefore, the pavement itself acts as the weighing device;

installation of an axle detecting device, which operates across an entire lane of interest, either surface mounted on the pavement or instrumented in the same borehole extrusion as the load sensing device; and

instrumentation capable of real-time data logging and analysis of the signals from the load sensing and axle detecting devices and displaying and/or transmitting the information in a suitable manner.

The preferred embodiment of the present invention provides a method and systems formed for weighing vehicles in motion as the wheels of the vehicle pass over the location of the sensing device(s) embedded deeply below the pavement, which may comprise the steps of:

providing a load measuring device configured in a suitable extrusion utilising a multiplicity of electrical strain gauges or a multiplicity of point fibre optic sensors or single distributed fibre optic sensors which respond to the load applied by the vehicle wheels as it passes over the location of the device and displaces the pavement;

providing a load measuring device installed in a borehole and at a suitable depth under the pavement surface and operating along the entire length of the device so as to cover the lane of interest;

optionally providing more than one instrumented borehole along the same wheel path as the first borehole

in order to have more than one weight measurement to average and possibly to provide additional information about the vehicle, such as speed, vehicle classification, axle spacings, number of tyres per axle, lane position, etc.;

providing a suitable number of axle detectors mounted on the surface of the pavement as closely co-directional and co-located with each of the instrumented boreholes as possible or mounted in each borehole load measuring extrusion in order to provide certain information about the event, such as vehicle number of axles, speed, vehicle classification, axle spacings, number of tyres per axle, lane position, etc.;

providing instrumentation associated with the load sensing device having output signals associated with the magnitude of load or displacement detected by the load sensing device;

providing instrumentation associated with the axle detectors having output signals associated with the occurrence and timing of the vehicle wheel passing over the axle detector locations;

providing automated system instrumentation which accepts the information from the load sensing device and axle detector instrumentation and suitably analyses, records, displays and transmits the information;

calibrating the installed load sensing device by a suitable industry recommended process involving passing a vehicle or a number of vehicles of known weight a number of times across the sensing device location, varying the vehicle weight and speed, to establish a statistically derived calibration factor for the WIM site;

optionally, if a number of load sensing devices are used at a WIM site then the system is calibrated as described above by a suitable average or weighted average of the responses from the load sensing devices;

providing the site calibration factor to the system instrumentation in order to maintain the system weight measurements within the required level of accuracy;

acquiring the output signals of the various devices in the system as a vehicle passes by the WIM site;

analysing the signal characteristics using suitable algorithms, taking into account the site calibration factor, so as to determine the weight and any other desired information (ie., speed, classification, etc.) for the vehicle; and

recording the vehicle information in a system database and displaying or transmitting the vehicle information locally and/or remotely.

The preferred embodiment of the present invention provides a method for installing a WIM load sensing device, and possibly axle detectors, in a borehole deeply below the pavement, which may comprise the steps of:

producing a suitable diameter, horizontal borehole across the pavement lane(s) of interest using any suitable boring techniques;

inserting the specially configured, instrumented extrusion into the borehole to the desired location;

filling the remaining borehole void with an epoxy filler, or any other suitable filler material;

protecting the sensor leads in a suitable manner, possibly running them in conduits to the WIM system instrument; and

restoring site of borehole entry to its original form, rendering the site invisible to vehicle operators.

The preferred embodiment of the present invention incorporates a data logger in the system instrumentation,

which consists of several opto-electronic and/or electronic cards housed in an enclosure. Several WIM sensor inputs can be provided, as well as axle detector inputs. The data logger matches up axle detections with strains produced by an axle travelling over the WIM sensor(s) and stores this information, along with the date/time, into the data logger's internal memory. The information is also available in real-time to allow the system to be used as part of a screening or enforcement system. In a preferred embodiment of the invention, a modem is connected to the system to provide remote data downloading or monitoring capability. The WIM system software allows local or remote monitoring of vehicles travelling over the WIM sensors. For each vehicle, typical parameters displayed are:

vehicle classification
axle/wheel configuration
vehicle speed
axle group masses
gross vehicle mass

In addition, many violation checks can be performed on each vehicle, including:

axle mass overload
axle group mass overload
gross vehicle mass overload
bridge formulae conformance
'pig' trailer dimensional conformance
avoidance

In a preferred embodiment, but without limitation, the instrumented extrusion is made from a PVC plastic U-channel. The electrical strain gauges or fibre optic sensors are suitably attached to the inner flat surface of

the PVC U-channel and the extrusion is then preferably filled with the same epoxy used to fill the borehole or any other suitable filler material. The instrumented and packaged extrusion is then ready to be inserted into the borehole. In other preferred embodiments, the extrusion with electrical strain gauges is not filled with the epoxy.

In another preferred embodiment, the extrusion comprises a flat metallic beam inserted into a PVC conduit. The electrical strain gauges or fibre optic sensors are suitably attached to a flat surface of the flat metallic beam. The instrumented beam is then inserted inside a PVC conduit and suitably fastened to the conduit. The conduit is then capped or sealed on both ends to prevent moisture ingress, with the sensor leads exiting though a suitable gland at one end of the conduit. The instrumented and packaged extrusion is then ready to be inserted into the borehole.

In other embodiments of the invention the extrusions are made from other suitable materials.

In a preferred embodiment of the invention, but without limitation, the boreholes are filled with a suitable epoxy filler to fill all voids. In other embodiments, any other suitable filler material may be used. In yet other embodiments, little or no filler may be used.

In a preferred embodiment of the invention, but without limitation, the borehole is produced such that it is horizontal across the pavement and at a perpendicular direction to the traffic flow. However, in other

embodiments the borehole may be used at any other desired angles.

In a preferred embodiment of the invention, but without limitation, more than one instrumented borehole may be used along the same wheel path, usually parallel to one another and spaced between 5 to 10 metres apart. Using multiple sensors should assist to decrease the measurement error by averaging-out wind, speed and rough pavement effects on vehicle suspensions, as well as enabling other vehicle parameters to be determined (ie., speed, axle spacing, lane position, etc.). The averaging of the multiple load sensing device signals may be non-weighted, weighted, linear or non-linear, as appropriate or suitable.

In a preferred embodiment utilising a multiplicity of borehole load sensing devices the boreholes run perpendicular to the direction of traffic flow and are parallel to one another. In other embodiments, the boreholes are arranged at any other desirable angle to the traffic flow and parallel to one another. In yet other embodiments, the boreholes are each arranged at any desirable angle to the traffic flow and not necessarily parallel to one another (ie., Z pattern).

In a preferred embodiment of the invention, but without limitation, the borehole is constructed at a typical depth of between 500 to 1,000 mm below the pavement surface, which is usually into the sub-grade material of the road. In other embodiments, however, this depth can be shallower or deeper, as appropriate.

In preferred embodiments of the invention, but without limitation, the load sensing devices are installed in boreholes deep under the pavement. However, in other embodiments any suitable method for installing the load sensing devices deeply in the pavement may be utilised.

In a preferred embodiment of the invention, but without limitation, a load-sensing device operates across an entire lane of interest. However, in other embodiments the load sensing devices may operate partially across one or more lanes. In yet other embodiments, the load sensing devices may operate across a number of lanes.

In a preferred embodiment of the invention, but without limitation, the WIM sensing system utilises axle detectors as well as the load sensing devices. In other embodiments, the WIM system may not utilise axle detectors. In yet other embodiments, the WIM system may use a plurality of sensing and monitoring devices, such as load sensing devices, axle detectors, video surveillance equipment, speed cameras, height detectors, remotely operated signage, visible alarms, audible alarms, electronic tag reading equipment, etc.

In a preferred embodiment of the invention, but without limitation, the axle detectors are co-directional and co-located with the load sensing devices, regardless of whether the axle detectors are installed on the surface of the road or in a borehole. In other embodiments of the invention, the axle detectors may be skewed.

In a preferred embodiment of the invention, but without limitation, the WIM system is a microprocessor based and fully automated instrument that can be monitored and

controlled locally and/or remotely. Preferably, the system instrumentation comprises hardware and software components.

In a preferred embodiment of the invention, but without limitation, calibration of the site is performed on commissioning of a system and on periodic intervals, as deemed necessary by the authorities, the client or changing site conditions.

Preferably, but without limitation, the system provides velocity independent, static weight equivalent values for the vehicles that pass over the WIM site.

In a preferred embodiment of the invention, but without limitation, each borehole extrusion contains at least one load sensor and one axle detector. In some embodiments, a plurality of sensors may be used. In yet other embodiments a plurality of varying types of sensors may be utilised.

In preferred embodiments of the invention, but without limitation, the inventions disclosed in this provisional specification may be used for screening or enforcement WIM applications.

In preferred embodiments of the invention, but without limitation, the inventions disclosed in this provisional specification may be used for static, low-speed or high-speed WIM applications.

In a preferred embodiment, but without limitation, the sensors used for the construction of the load-sensing

device are a series of eight electrical strain gauges or strain gauged strain amplifiers distributed across the length of the specially configured extrusion for a single lane width. An average or weighted average of the responses of the strain gauges is used to determine the load applied by a passing vehicle. With this arrangement it may also be possible to determine the wheel lane positions for a vehicle. In other embodiments, a smaller or greater number of electrical strain gauges or strain gauged strain amplifiers are used. In yet other embodiments, point-sensitive fibre optic sensors are used in place of electrical strain gauges.

In a preferred embodiment of the invention, but without limitation, the axle detector is a conventional piezo-electric strip installed in the surface of the pavement. In another preferred embodiment, but without limitation, a novel linear modalmetric interferometer is utilised as an axle detector inserted into saw-cuts on the surface of pavements or in the borehole extrusion. In other embodiments, any suitable sensing device, including piezo-electric strips, other fibre optic sensors, or the same strain gauge or fibre optic systems used in the load sensing devices, may be utilised for axle detection installed either in the surface of the pavement, embedded in the pavement or in a borehole extrusion under the pavement.

In a preferred embodiment, but without limitation, a single distributed fibre optic sensor is used for the construction of the load-sensing device across the length of the specially configured extrusion. In a preferred embodiment, the distributed fibre optic sensing technique is one of the two interferometric techniques disclosed below. In a preferred embodiment, the fibre optic interferometer should have a sensor gauge length that is

many multiples of the extrusion/lane length. With this capability, the fibre can be looped at the extreme ends of the desired sensing region of the extrusion so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times. Recent developments in the telecommunications industry of lower-cost solid state lasers with long coherence lengths now make it possible to extend the sensing length of interferometers, if configured correctly, to over 40 m. Previously, this would have required a relatively expensive, bulky and highly-stabilised gas laser, with demanding power requirements. The two interferometric techniques are further detailed below:

Fibre Optic Michelson Interferometer

In the method, according to a preferred embodiment of the invention, highly coherent electromagnetic radiation at the appropriate sensing wavelength is launched into a singlemoded optical waveguide, such as an optical fibre, from a light source, such as a pigtailed DFB laser diode or fibre laser, preferably of a Bragg grating stabilised format, and propagates along the optical waveguide. Preferably a DFB laser diode with a coherence length of at least 60 metres is utilised. The optical waveguide is fusion spliced, or otherwise connected (temporarily or permanently), to one input arm of a singlemode optical waveguide isolator and when the electromagnetic radiation reaches the isolator the electromagnetic radiation can only propagate out into the output waveguide arm of the isolator. The electromagnetic radiation cannot propagate in the reverse direction through the isolator, thus optical reflections are stopped from possibly destabilising the DFB laser diode. The output waveguide arm of the isolator is then fusion spliced, or otherwise connected (temporarily or permanently), to one input arm of an optical waveguide light splitter or coupler (singlemoded) and when the

electromagnetic radiation reaches the coupler the electromagnetic radiation can branch out into the output waveguide arms of the coupler. Thus, simultaneously, electromagnetic radiation is launched into the output waveguide arms of the coupler. The output arms of the coupler are fusion spliced, or otherwise connected (temporarily or permanently), directly to a reference arm and a sensing arm of the Michelson interferometer. Preferably, the sensing arm is longer than the reference arm. The sensing arm is then the part of the waveguide sensor that should be exposed to the sensing region of interest (ie., bonded to the specially configured extrusion). The two interferometer arms are mirrored and the electromagnetic radiation signals are then recombined in the coupler to mix coherently and form a "fringe pattern" which is directly related to the optical phase difference experienced between the different optical beams (between the sensing arm and the reference arm). The fringe pattern optical signal is then branched out into two separate output arms of the coupler (in the opposite direction to the original light input). Electromagnetic radiation that propagates in the coupler arm towards the isolator and light source is attenuated by the isolator and prevented from being launched into the laser diode. The other output arm of the coupler is then terminated at an appropriate photodetector. Appropriate electronics, signal processing schemes and algorithms process the signals from the photodetector to obtain the desired information. Fringe counting (counting maxima or minima of the sensor output) can thus be performed in order to monitor any external parameters acting on the sensing arm.

Fibre Optic Fabry-Perot Interferometer

The Fabry-Perot interferometer has the simplest configuration of all the fibre optic interferometers as it is essentially an optical cavity comprising of two mirror surfaces adjusted to be perfectly parallel to each other and perpendicular to the axis of the optical fibre. A change in the optical path length of the cavity, due to some external parameter, results in a phase retardance of the cavity modes. In the back-reflected configuration and low-Finesse cavities, the sensor output is very similar to that of the Michelson interferometer. Therefore to monitor any external parameters fringe counting (counting maxima or minima of the sensor output) can be performed.

Therefore, in the method, according to a second preferred embodiment of the invention, highly coherent electromagnetic radiation at the appropriate sensing wavelength is launched into a singlemoded optical waveguide, such as an optical fibre, from a light source, such as a pigtailed DFB laser diode or fibre laser, preferably of a Bragg grating stabilised format, and propagates along the optical waveguide. Preferably a DFB laser diode with a coherence length of at least 60 metres is utilised. The optical waveguide is fusion spliced, or otherwise connected (temporarily or permanently), to one input arm of a singlemode optical waveguide isolator and when the electromagnetic radiation reaches the isolator the electromagnetic radiation can only propagate out into the output waveguide arm of the isolator. The electromagnetic radiation cannot propagate in the reverse direction through the isolator, thus optical reflections are stopped from possibly destabilising the DFB laser diode. The output waveguide arm of the isolator is then fusion spliced, or otherwise connected (temporarily or permanently), to one input arm of an optical waveguide

light splitter or coupler (singlemoded) and when the electromagnetic radiation reaches the coupler the electromagnetic radiation can branch out into the output waveguide arms of the coupler. One of the output waveguide arms of the coupler is unused and is fractured or otherwise terminated to avoid back-reflections. Thus, the electromagnetic radiation continues to propagate along only one of the output waveguide arms of the coupler. The output arm of the coupler is fusion spliced, or otherwise connected (temporarily or permanently), directly to the Fabry-Perot interferometer optical waveguide (singlemoded). The two mirrors of the interferometer are provided for by having a suitable Bragg grating at the start of the desired sensing region and the end of the optical waveguide is terminated with a mirror. The sensitive region of the sensing optical waveguide (between the grating and the end-mirror) is then the part of the waveguide sensor that should be exposed to the sensing region of interest (ie., bonded to the specially configured extrusion). Preferably, the interferometer is operated in a back-reflected configuration and designed to have a low-Finesse cavity. Thus, a change in the optical path length of the cavity (between the Bragg grating and the end-mirror), due to some external parameter, results in a phase retardance of the cavity modes and producing a response very similar to that of the Michelson interferometer (forming a "fringe pattern" which is directly related to the optical phase difference experienced between the different optical beams). The fringe pattern optical signal is then branched out into two separate output arms of the coupler (in the opposite direction to the original light input). Electromagnetic radiation that propagates in the coupler arm towards the isolator and light source is attenuated by the isolator and prevented from being launched into the laser diode. The other output arm of the coupler is then terminated at an

appropriate photodetector. Appropriate electronics, signal processing schemes and algorithms process the signals from the photodetector to obtain the desired information.

The Fabry-Perot fibre optic sensor is extremely attractive as a fibre optic sensor due to it's single-fibre configuration, incorporating the lead-in, lead-out signals and common mode rejection into a single optical fibre, and due to its very high sensitivity with extremely good spatial and directional localisation characteristics.

All interferometers exhibit a sinusoidal or non-linear response to externally applied force. This non-linear relationship leads to a problem of signal fading and ambiguity in the direction of phase change (i.e. increasing or decreasing load). This problem can be solved by operating the sensor in its constant linear sensitivity range, otherwise known as the quadrature condition. The response signal is then processed through a signal processing system for phase demodulation and recovery. This is commonly known as quadrature phase demodulation.

Several techniques have been developed to achieve a linearisation of an interferometer's response. The passive homodyne technique is the most suitable for field applications and requires an interferometer configuration such that there are two output signals separated by a constant phase difference of $\pi/2$ (90°). One technique by which this is accomplished is by the use of a 3x3 six port or 4x4 eight port fibre directional coupler. The use of a

3x3 or 4x4 coupler produces, in general ($\pi/3$ for the 3x3) and exactly ($\pi/2$ for the 4x4), a sine and cosine signal:

$$I_1 = A\ (1 + \sin\theta)$$

(1)

$$I_2 = A\ (1 + \cos\theta)$$

where A is a constant factor and θ is the differential optical phase shift induced in the sensing region. These signals are detected by two photodetectors and processed to recover the phase.

Preferably the fibre optic interferometric sensors used in the WIM systems described in this provisional specification utilise passive quadrature phase demodulation to automate the fringe counting, resulting in an automated, unambiguous strain monitoring capability. In other embodiments other suitable phase demodulation or fringe counting techniques, such as active phase demodulation, are used.

Preferably, if a 3x3 or 4x4 coupler is used the unused arms are fractured or otherwise terminated to avoid back-reflections.

In a preferred embodiment of the invention, but without limitation, the silica waveguide is a singlemoded fibre at the sensing wavelength and the lead waveguides are singlemode fibres at the sensing wavelength.

In a preferred embodiment of the invention, but without limitation, all the optical fibres and fibre devices are connected by fusion splices. In other embodiments the optical fibres and fibre devices may be connected by any

suitable or appropriate technique, such as mechanical splices, connectorised leads and through-adaptors, etc.

The effective sensing length of the waveguide sensor can be varied for either point or integrated sensitivity. Multi-point sensing can be achieved by quasi-distributed, distributed or multiplexed configurations.

Preferably the waveguide comprises at least one optical fibre and/or at least one optical fibre device. In some embodiments of the invention the waveguide may merely comprise an optical fibre without any additional sensing elements. However, the optical fibre can include sensing elements at its end or along its length and those sensing elements can comprise devices which will respond to a change in the desired parameter in the environment of application and influence the properties and characteristics of the electromagnetic radiation propagating in the waveguide to thereby provide an indication of the change in the parameter.

The waveguide or waveguides may be formed from any glass material, hard oxides, halides, crystals, sol-gel glass or polymeric material, or may be any form of monolithic substrate.

Preferably the detector means comprises:

a photodetector for receiving the transmitted or reflected radiation from the sensing signal in the silica waveguide; and

processing means for receiving signals from the photodetector and analysing the signals in order to register the sensed events.

Preferably any suitable CW or pulsed single or multiple wavelength source or plurality of sources may be employed. In a preferred embodiment, without limitation, a CW or pulsed high coherence DFB laser diode is utilised to supply the optical signal. In an alternate arrangement, multiple light sources, of the same or varying wavelengths, may be used to generate the sensing signal or a plurality of sensing signals.

Preferred embodiments of the present invention offer the potential to utilise all-fibre, low-cost optical devices in conjunction with laser diodes, photodetectors, isolators, couplers, WDM couplers and filters.

In preferred embodiments of the present invention any suitable light source, coupler and photodetector arrangement may be used with the sensor systems. In a preferred embodiment, the required optical properties of the light source are such that the sensor gauge length is many multiples of the extrusion/lane length. With this capability, the fibre can be looped at the extreme ends of the desired sensing region of the extrusion so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times.

In preferred embodiments of the present invention, without limitation, lead-in and lead-out fibre desensitisation and sensor localisation is achieved. In other embodiments it may be possible to have lead-in or lead-out sensitivity or no sensor localisation.

Preferably, but without limitation, utilisation of properties and characteristics of the electromagnetic radiation propagating in the waveguide sensor enables

monitoring to take place in a non-destructive manner. Thus, the sensor is not necessarily damaged, fractured or destroyed in order to monitor and locate the desired parameter.

A preferred method for mirroring the optical fibre end-face involves placing the fibre in a vacuum system and the prepared fibre end-face is then coated with a metallic material such as Au, Ag, Al or Ti or a dielectric material such as TiO_2. This coating can be prepared by using thermal evaporation, electron beam evaporation or sputtering. Other coating or mirroring materials and techniques may also be utilised.

In preferred embodiments of the present invention, without limitation, the manufactured sensor and/or the exposed fusion spliced region may be protected by encapsulating or coating the desired region in fusion splice protectors or any suitable material (ie. ultraviolet acrylate, epoxy, etc).

Preferably the instrument optical and electronic arrangements will utilise noise minimisation techniques.

Preferably, all the optical and electrical components will be located in a single instrument control box, with individual optical fibre input/output ports.

Optical devices, electro-optic devices, acousto-optic devices, magneto-optic devices and/or integrated optical devices may also be utilised in the system.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention will be further illustrated, by way of example, with reference to the following drawings in which:

Figure 1 is a view showing a general embodiment of the load sensing device of the present invention, utilising the U-channel extrusion;

Figure 2 is a view showing a general embodiment of the load sensing device of the invention for the flat beam inserted into a conduit extrusion;

Figure 3 is a view showing a general embodiment of the invention for a configuration of electrical strain gauges or strain gauged strain amplifiers attached to the extrusion;

Figure 4 is a view showing a general embodiment of the invention for a configuration of a single length of fibre optic sensor attached to the extrusion;

Figure 5 is a view showing a general embodiment of the invention for a configuration of a fibre optic sensor gauge length that is many multiples of the extrusion/lane length attached to the extrusion, such that the fibre is looped at the extreme ends of the desired sensing region of the extrusion so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times;

Figure 6 is a view showing a general embodiment of the invention for the borehole configuration from a cross-sectional top view;

Figure 7 is a view showing a general embodiment of the invention for the borehole configuration from a cross-sectional side view and utilising a surface attached axle detector;

Figure 8 is a view showing a general embodiment of the invention for the borehole configuration from a

cross-sectional side view and utilising a borehole installed axle detector;

Figure 9 is a view showing a general embodiment of the invention for the borehole configuration from a cross-sectional trench-end view;

Figure 10 is a view showing a general embodiment of the invention for the fibre optic Michelson interferometer;

Figure 11 is a view showing a general embodiment of the invention for the fibre optic Michelson interferometer utilising a passive homodyne demodulation configuration;

Figure 12 is a view showing a general embodiment of the invention for the fibre optic Fabry-Perot interferometer;

Figure 13 is a view showing a general embodiment of the invention for the fibre optic linear modalmetric interferometer [33] utilised as an axle detector;

Figure 14 is a view showing a general embodiment of the invention for a complete WIM system utilising load sensing devices in two instrumented boreholes; and

Figure 15 is a view showing the response of the fibre optic linear modalmetric interferometer utilised as an axle detector.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the invention, without imposing any limitations, will be further described with reference to the above mentioned drawings. The drawings and the following embodiments are provided in as general a form as possible to avoid confusion. While it may not be specifically stated or illustrated in the following embodiments and drawings, in the preferred embodiments the

following features are utilised, and not intentionally omitted, where appropriate:

1. suitable electrical and/or optical devices are employed at one or both ends of the system to detect and process the signals;

2. utilisation of properties and characteristics of the electromagnetic radiation propagating in the waveguide sensor enables monitoring to take place in a non-destructive manner. Thus, the sensor is not necessarily damaged, fractured or destroyed in order to monitor the desired parameter;

3. utilisation of all-fibre, low-cost optical devices in conjunction with laser diodes, photodetectors, couplers, WDM couplers, isolators and filters;

4. the wavelength couplers are 2x2 3dB couplers, in other embodiments they may be any suitable multi-port device, such as 2x1, 3x1, 3x3, 4x4, etc.; and

5. the optical fibres and fibre devices are connected by fusion splices. In other embodiments the optical fibres and fibre devices are connected by any suitable or appropriate technique, such as mechanical splices, connectorised leads and through-adaptors, etc.

Figure 1 illustrates a substrate in the form of a U-channel extrusion utilised in a general embodiment of the load sensing device 50 (Figs 3-5) of the present invention. The substrate 2 includes a flat base 2b and two upstanding side walls 2a, 2c.

Figure 2 illustrates the substrate 2 in the form of a flat beam 4 inserted into a conduit extrusion 6 utilised in

another general embodiment of the load sensing device 50 (Figs 3-5) of the present invention. The substrate 4 may be extruded as a single article or the beam 4 and conduit 6 may be separate extrusions. Furthermore, the beam 4 and extrusions 6 can be formed from the same or different material.

Figure 3 is a view showing an embodiment of the device 50 in the form of a configuration of electrical strain gauges or strain gauged strain amplifiers 12 attached to the inner flat base 2b of the U-channel 2 or the flat beam 4.

Figure 4 is a view showing a further embodiment of the device 50 in the form of a single length of fibre optic sensor 22 attached to the inner flat base 2b of the U-channel 2 or the flat beam 4.

Figure 5 is a view showing a further embodiments of the device 50 in the form of a fibre optic sensor gauge length that is many multiples of the length of the device 50, attached to the inner flat base 2b of the U-channel 2 or the flat beam 4, such that the fibre is looped 26 at the extreme ends of the desired sensing region of the extrusion so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times.

Figures 6-9 show embodiments of the invention. With reference to Figure 6, according to a preferred embodiment of the present invention, a suitable diameter, horizontal borehole 34 is made across the pavement 30 and lane 32 of interest using any suitable boring technique. Following installation of the load measuring device 50 and an axle detector 52 into the borehole 34, the site of borehole

entry 38 is restored to its original form, rendering the site invisible to vehicles.

Figure 7 is a view showing a general embodiment of the invention for the borehole configuration from a cross-sectional side view and utilising a surface attached axle detector 52. With reference to Figure 7, according to a preferred embodiment of the present invention, a suitable diameter, horizontal borehole 34 is made across the pavement 30 and lane 32 of interest using any suitable boring technique. The borehole 34 is constructed at a typical depth of between 500 to 1,000 mm below the pavement 30 surface, which is usually into the sub-grade material 36 of the road. The load measuring device 50 is inserted in the borehole 34 operating along the entire length of the device so as to cover the lane 32 of interest. After inserting the load measuring device 50, the remaining borehole void 35 is filled with an epoxy filler. An axle detector 52 is mounted on the surface of the pavement 30 as closely co-directional and co-located with the instrumented borehole 34 as possible in order to provide certain information. The load measuring device 50 has sensor leads 54 which are protected in a suitable manner where they exit the borehole 34 and run in conduits 59 to the WIM system instrumentation 40. Likewise, the axle detector 52 has leads 53 which are protected in a suitable manner where they exit the pavement 30 and run in conduits 59 to the WIM system instrumentation 40. Finally, the site of borehole entry 38 is restored to its original form, rendering the site invisible to vehicles.

Figure 8 is a view showing a general embodiment of the invention for the borehole configuration from a cross-sectional side view and utilising a borehole installed axle detector 52. With reference to Figure 8, according to a preferred embodiment of the present invention, a

suitable diameter, horizontal borehole 34 is made across the pavement 30 and lane 32 of interest using any suitable boring technique. The borehole 34 is constructed at a typical depth of between 500 to 1,000 mm below the pavement 30 surface, which is usually into the sub-grade material 36 of the road. A load measuring device 50 is inserted in the borehole 34 operating along the entire length of the device so as to cover the lane 32 of interest. After inserting the load measuring device 50, the remaining borehole void 35 is filled with an epoxy filler. An axle detector 52 is also mounted on the extrusion 2 or 4 of the device 50 in order to provide certain information. The load measuring device 50 has sensor leads 54 and the axle detector 52 has leads 54 which are protected in a suitable manner where they exit the borehole 34 and run in conduits 59 to the WIM system instrumentation 40. Finally, the site of borehole entry 38 is restored to its original form, rendering the site invisible to vehicles.

Figure 9 is a view showing a general embodiment of the invention for the borehole configuration from a cross-sectional trench-end view. With reference to Figure 9, according to a preferred embodiment of the present invention, a trench 38 is dug beside the road for the boring equipment to gain access to the appropriate depth under the pavement 30 for the construction of the WIM borehole 34. A suitable diameter, horizontal borehole 34 is made across the pavement 30 and lane 32 of interest using any suitable boring technique. The borehole 34 is constructed at a typical depth of between 500 to 1,000 mm below the surface of the pavement 30, which is usually into the sub-grade material 36 of the road. Following installation of the load measuring device 50 and axle detector 52 into the borehole 34, the site of borehole

entry 38 is restored to its original form, rendering the site invisible to vehicles.

The purpose of the load measuring device 50 is to provide a measure of the actual load applied to the load measuring device 50 and therefore the weight of a vehicle travelling over the pavement 30 and over the load measuring device 50. Thus, the load measuring device 50 may provide an indication of the weight of the vehicle such as 40 tonne or the like. The purpose of the axle measuring device 42 is to provide an indication of the number of axles the vehicle actually has so that this information can be combined with the load information if desired to determined whether the vehicle is carrying a load which is within legal limits or whether the load is outside legal limits. In order to provide this assessment it is necessary to have some information as to the nature of the vehicle because, for example, a load of 40 tonnes may not be suitable for a vehicle having four axles but may be within legal limits of a vehicle having eight axles. Thus, the information which is derived from the load measuring device 50 is a quantitised value indicating the weight of the vehicle and the information from the axle detector 52 merely provides an indication of the number of axles on the vehicle. The axle detector 52 may be comprised of a piezo-electric strip or optical fibre construction (as will be described hereinafter) which, as described in the above embodiments, can be applied across the surface of the pavement 30 of the lane 32 or can be included in the borehole 34 along with the device 50. The piezo-electric strip or fibre which forms the detector 52 simply provides an output when the vehicle wheels roll over the device. The time difference between the peaks of the output (indicating the presence of a vehicle wheel on the device) is used to determine the number of axles of the vehicle. This time difference is therefore able to

discriminate one vehicle from another and allow an assessment to be made as to whether a particular vehicle has two, four, eight or even more axles. In the simplest embodiment of the invention the detector 52 simply comprises a single strip which runs across the lane 32 in a direction perpendicular to the direction of traffic flow. However, in other embodiments the device 52 may be in the form a Z-shaped pattern having two arms which are arranged perpendicular to the direction of traffic flow and a joining arm extending from opposed ends of the other arms and which is arranged at an acute angle with respect to the direction of traffic flow. This Z-shaped arrangement can also provide information as to the position of the vehicle within a particular lane 32 because the time difference between a vehicle wheel contacting one of the arms which is perpendicular and then contacting the arm which is arranged at an acute angle with respect to the traffic flow will differ depending on where the vehicle is in the particular lane. Thus, the time measurement between contact of the perpendicular arms and the contact of the acute arm can be used to provide an indication of the position of the vehicle within a particular lane 32.

Thus, the purpose of the axle detector 52 is merely to switch on and off as an axle of a vehicle travels over the detector 52 thereby enabling the indication of the presence of an axle to be determined and time differences between peaks (ie the time the detector is on) to provide an indication of the number of axles, whereas the device 50 provides quantity information which gives a measure of the actual weight or load of the vehicle travelling over the device 50.

Figure 10 is a view showing a general embodiment of the invention for the fibre optic Michelson interferometer

utilised to instrument the load measuring device. With reference to Figure 10, according to a preferred embodiment of the present invention, CW coherent laser light is launched into a singlemode optical fibre 15, from a pigtailed DFB laser diode 60 and fibre isolator 62, and propagates along the optical fibre 15. Preferably, a DFB laser diode with a coherence length of at least 60 metres is utilised. The optical fibre 15 is terminated at a singlemode fibre optic bulkhead connector (through adaptor) 64a. A jacketed, connectorised singlemode fibre lead 16a is connected to the through adaptor 64a, such that the light from the optical fibre 15 is launched into the fibre lead 16a. The optical fibre lead 16a is fusion spliced 66 to one arm 66 of a singlemode 2x2, 3 dB fibre optic coupler 70 and when the light reaches the coupler 70 the light can branch out into the two output arms 72 and 78 of the coupler 70. Thus, coherent laser light is simultaneously launched into the two output arms 72 and 78 of the coupler 70. The two output arms 72 and 78 of the coupler 70 are fusion spliced 74 and 80 directly to a reference arm 12 and a sensing arm 10 of the Michelson interferometer. The reference arm 12 is made as short as practicable (around 100 mm). The sensing arm 10 is then the part of the fibre sensor that should be bonded to the sensing region of the specially configured extrusion 2 or 4. The fibre sensing arm 10 length should be made many multiples of the extrusion/lane length 2/4 or 32 such that the fibre 10 is looped 26 at the extreme ends of the desired sensing region of the extrusion 2 or 4 so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times. The reference 12 and sensing 10 arms are mirrored 76a and 76b and the laser light signals are then reflected back to recombine in the coupler 70 to mix coherently and form a "fringe pattern" which is directly related to the optical phase difference experienced between the different optical beams (between the sensing arm 10 and the reference arm

12). The fringe pattern optical signal is then branched out into two separate output arms 68 and 82 of the coupler 70, in the opposite direction to the original light input. The optical signal in coupler arm 68 propagates towards the isolator 62 and DFB laser diode 60 and is attenuated by the isolator 62 and prevented from being launched into the laser diode 60. The optical signal in coupler output arm 82 propagates through fibre splice 84 and along a jacketed, connectorised singlemode fibre lead 16b to a singlemode fibre optic bulkhead connector (through adaptor) 64b. This optical signal is then launched into an optical fibre 17 that is terminated at an appropriate photodetector 86. Appropriate electronics, signal processing schemes and algorithms process the signals from the photodetector 86 to obtain the desired information. Fringe counting (counting maxima or minima of the sensor output) can thus be performed in order to monitor any external parameters acting on the sensing arm 10. For practical field implementation and obtaining total sensor lead insensitivity, all items within the box marked 2/4 are incorporated in the extrusion 2 or 4. All items within the box marked 20 are incorporated in the load sensing device instrumentation 20 of the WIM system instrumentation 40. Additionally, the insensitive fibre optic leads 16a and 16b may be made sufficiently long as to allow the load sensing device 50 to be remotely located from the load sensing device instrumentation 20. The insensitive fibre optic leads 16a and 16b will normally run in a conduit 59 to the load sensing device instrumentation 20.

Figure 11 is a view showing a general embodiment of the invention for the fibre optic Michelson interferometer utilising a passive homodyne demodulation configuration. With reference to Figure 11, according to another preferred embodiment of the present invention, CW coherent

laser light is launched into a singlemode optical fibre 15, from a pigtailed DFB laser diode 60 and fibre isolator 62, and propagates along the optical fibre 15. Preferably, a DFB laser diode with a coherence length of at least 60 metres is utilised. The optical fibre 15 is terminated at a singlemode fibre optic bulkhead connector (through adaptor) 64a. A jacketed, connectorised singlemode fibre lead 16a is connected to the through adaptor 64a, such that the light from the optical fibre 15 is launched into the fibre lead 16a. The optical fibre lead 16a is fusion spliced 66 to one arm 68 of a singlemode 3x3 unitary fibre optic coupler 88 and when the light reaches the coupler 88 the light can branch out into the three output arms 72, 78 and 79 of the coupler 88. Thus, coherent laser light is simultaneously launched into the three output arms 72, 78 and 79 of the coupler 88. One output arm 79 of the coupler 88 is fractured or otherwise terminated 89 to avoid back-reflections. The remaining two output arms 72 and 78 of the coupler 88 are fusion spliced 74 and 80 directly to a reference arm 16 and a sensing arm 14 of the Michelson interferometer. The reference arm 16 is made as short as practicable (around 100 mm). The sensing arm 14 is then the part of the fibre sensor that should be bonded to the sensing region of the specially configured extrusion 2 or 4. The fibre sensing arm 14 length should be made many multiples of the extrusion/lane length 2/4 or 32 such that the fibre 14 is looped 26 at the extreme ends of the desired sensing region of the extrusion 2 or 4 so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times. The reference 16 and sensing 14 arms are mirrored 76a and 76b and the laser light signals are then reflected back to recombine in the coupler 88 to mix coherently and form a "fringe pattern" which is directly related to the optical phase difference experienced between the different optical beams (between the sensing arm 14 and the reference arm 16). The fringe

pattern optical signal is then branched out into the three separate output arms 68, 82b and 82c of the coupler 88, in the opposite direction to the original light input. The optical signal in coupler arm 68 propagates towards the isolator 62 and DFB laser diode 60 and is attenuated by the isolator 62 and prevented from being launched into the laser diode 60. The optical signals in coupler output arms 82b and 82c propagate through fibre splices 84b and 84c and along jacketed, connectorised singlemode fibre leads 16b and 16c to singlemode fibre optic bulkhead connectors (through adaptors) 64b and 64c. These optical signals are then launched into optical fibres 17b and 17c, which are terminated at appropriate photodetectors 86b and 86c. Appropriate electronics, signal processing schemes and algorithms process the signals from the photodetectors 86b and 86c to obtain the desired information. Automated fringe tracking (strain monitoring) can thus be performed using suitable quadrature phase demodulation algorithms in order to monitor any external parameters acting on the sensing arm 14. For practical field implementation and obtaining total sensor lead insensitivity, all items within the box marked 2/4 are incorporated in the extrusion 2 or 4. All items within the box marked 20 are incorporated in the load sensing device instrumentation 20 of the WIM system instrumentation 40. Additionally, the insensitive fibre optic leads 16a, 16b and 16c may be made sufficiently long as to allow the load sensing device 50 to be remotely located from the load sensing device instrumentation 20. The insensitive fibre optic leads 16a, 16b and 16c will normally run in a conduit 59 to the load sensing device instrumentation 20.

Figure 12 is a view showing a general embodiment of the invention for the fibre optic Fabry-Perot interferometer. With reference to Figure 12, according to a further preferred embodiment of the invention, CW coherent laser

light is launched into a singlemode optical fibre 15, from a pigtailed DFB laser diode 60 and fibre isolator 62, and propagates along the optical fibre 15. Preferably, a DFB laser diode with a coherence length of at least 60 metres is utilised. The optical fibre 15 is then fusion spliced 90 to one input arm 92 of a singlemode 2x2, 3 dB fibre optic coupler 70 and when the light reaches the coupler 70 the light can branch out into the two output arms 72 and 78 of the coupler 70. The output arm 78 of the coupler 70 is unused and is fractured or otherwise terminated 89 to avoid back-reflections. Thus, the coherent laser light continues to propagate along only one of the output arms 72 of the coupler 70. The output arm 72 of the coupler 70 is then terminated at a singlemode fibre optic bulkhead connector (through adaptor) 64. A jacketed, connectorised singlemode fibre lead 16 is connected to the through adaptor 64, such that the light from the output arm 72 of the coupler 70 is launched into the fibre lead 16. The optical fibre lead 16 is fusion spliced 94 directly to the singlemode sensing arm 18 of the Fabry-Perot interferometer. The two mirrors of the interferometer are provided for by having a suitable Bragg grating 96 at the start of the desired sensing region and the end of the sensing fibre 18 is terminated with a mirror 76. The sensitive region of the sensing fibre 18 (between the Bragg grating 96 and the end-mirror 76) is then the part of the fibre sensor that should be bonded to the sensing region of the specially configured extrusion 2 or 4. The fibre sensing arm 18 length should be made many multiples of the extrusion/lane length 2/4 or 32 such that the fibre 18 is looped 26 at the extreme ends of the desired sensing region of the extrusion 2 or 4 so as to traverse the sensing region a multiple number of times, thus increasing sensitivity a multiple number of times. In this configuration, the interferometer is operated in a back-reflected configuration and designed to have a low-Finesse cavity. Thus, a change in the optical path length of the

cavity (between the Bragg grating 96 and the end-mirror 76), due to an applied load, results in a phase retardance of the cavity modes and produces a response very similar to that of the Michelson interferometer (forming a "fringe pattern" which is directly related to the optical phase difference experienced between the different optical beams). Thus, the fringe pattern optical signal is then reflected back through fibre lead 16 and through adaptor 64, into the input arm 72 of the coupler 70 and branched out into two separate output arms 92 and 98 of the coupler 70, in the opposite direction to the original light input. The optical signal in coupler arm 92 propagates towards the isolator 62 and DFB laser diode 60 and is attenuated by the isolator 62 and prevented from being launched into the laser diode 60. The optical signal in coupler output arm 98 propagates through fibre splice 99, into an appropriate optical fibre terminated photodetector 86. Appropriate electronics, signal processing schemes and algorithms process the signals from the photodetector 86 to obtain the desired information. Fringe counting (counting maxima or minima of the sensor output) can thus be performed in order to monitor any external parameters acting on the sensing arm 18. For practical field implementation and obtaining total sensor lead insensitivity, all items within the box marked 2/4 are incorporated in the extrusion 2 or 4. All items within the box marked 20 are incorporated in the load sensing device instrumentation 20 of the WIM system instrumentation 40. Additionally, the insensitive fibre optic lead 16 may be made sufficiently long as to allow the load sensing device 50 to be remotely located from the load sensing device instrumentation 20. The insensitive fibre optic leads 16 will normally run in a conduit 59 to the load sensing device instrumentation 20.

Figure 13 is a view showing a general embodiment of the invention for the fibre optic linear modalmetric interferometer utilised as the axle detector 52. With reference to Figure 13, according to a preferred embodiment of the invention, a fibre optic modalmetric sensor 110 comprises a multimode fibre 118 which is mirrored on it's end-face 115 and fusion spliced 117 to a singlemode fibre patch cord 116. The free end of the fibre optic modalmetric sensor 110 is attached or bonded to the sensing region of the specially configured extrusion 2 or 4. The singlemode fibre patch cord 116 is coupled to instrumentation 120, which includes a light source 122, coupler 126 and a photodetector 124 and signal processing unit 42. The output arm 132 of the coupler 126 is unused and is fractured or otherwise terminated 128 to avoid back-reflections. Thus, the laser light continues to propagate along only one of the output arms 134 of the coupler 126. The output arm 134 of the coupler 126 is then terminated at a singlemode fibre optic bulkhead connector (through adaptor) 130. A jacketed, connectorised singlemode fibre lead 116 is connected to the through adaptor 130, such that the light from the output arm 134 of the coupler 126 is launched into the fibre lead 116. The light source 122 provides light which is propagated along the singlemode fibre 114 in the singlemode fibre patch cord 116 and, which in the embodiment of figure 13, is reflected back along the optical fibres 110 and 116 for detection by the photodetector 124. However, in other embodiments the detecting unit 124 could be located at the end of the optical fibre 110 and the laser light could merely be detected by the unit 124 without the need for reflection. The propagated light in the multimode fibre 118, which is eventually detected by the detector unit 124, has its properties and characteristics altered by a change in the load or strain experience by the sensing fibre 118. Figure 15 illustrates the response for a 1-2-3 axle

vehicle driving over a borehole-installed axle detector 52 using this method.

Figure 14 is a view showing a general embodiment of the invention for a complete WIM system utilising load measuring devices in two instrumented boreholes. Figure 14 is a general embodiment in which any of the electrical strain gauge or fibre optic sensors methods described above may be used in the load measuring device 50, axle detector 52 may be either surface or borehole installed and axle detectors 52/56 may be any suitable sensing device, including piezo-electric strips, the fibre optic linear modalmetric interferometer described in Figure 16, or the same strain gauge or fibre optic systems used in the load measuring device 50.

With reference to Figure 14, according to a preferred embodiment of the present invention, a pair of suitable diameter, horizontal boreholes 34 are made across the pavement 30 lane 32 of interest using any suitable boring technique. The boreholes 34 are constructed at a typical depth of between 500 to 1,000 mm below the pavement 30 surface, which is usually into the sub-grade material of the road. A load measuring device 50 is inserted into each of the boreholes 34 operating along the entire length of the device so as to cover the lane 32 of interest. After inserting the load measuring devices 50, the remaining borehole voids are filled with an epoxy filler. Axle detectors 52 are also mounted either on the pavement 30 surface or in the borehole load measuring devices 50 in order to provide certain information. The load measuring devices 50 sensor leads 54 and the axle detectors 52 leads 53 are protected in a suitable manner where they exit the boreholes 34 and run in one or more conduits 59 to the WIM system instrumentation 40. The site of borehole entry is restored to its original form, rendering the site

invisible to vehicles. The sensor leads 54 and 53 terminate in their respective sensing device instrumentation 20 housed in an instrumentation rack 42, where all the appropriate electronics, signal processing schemes and algorithms process the signals from the various sensors. The sensor information is then transferred to the WIM system PC 44, which analyses, records, displays and transmits the final information to the system operator. In some embodiments, the WIM system PC 44 is not located locally, but it is communicated to remotely by the WIM system instrumentation 40.

APPLICATIONS OF THE PREFERRED EMBODIMENTS

The development of a flexibly-sited, enforcement quality WIM system based on the inventions disclosed in this provisional application should open a new market segment with worldwide application and commercialisation potential. Many road authorities are seeking this type of equipment by trialing existing technologies, however, the very high accuracy and reliability demanded at highway speeds for enforcement, and the need for ease of installation, have thwarted these attempts. Market research, to date, indicates that the method and systems disclosed in this provisional specification offer the world's first practical, commercially viable, enforcement quality WIM systems.

Direct discussions with the industry have verified that there is very good commercial potential for the disclosed inventions, if the systems are cost effective, easy to install, do not require a culvert, do not require road closures, are at least as accurate as CULWAY, have low power consumption, are easy to use and invisible to road users. This is a lot to ask for in a WIM system, but

achievable with the inventions disclosed in this provisional specification.

It is important to note that the technology is considered to have good potential over competing techniques particularly because of the simplicity of sensor installation into the pavement, the excellent potential for system automation (ie., using cameras and remote communications) and reduction in the required installation and operational infrastructure costs.

Not inclusively, but indicatively, the following examples illustrates some applications in which a system according to the present invention may be used:

Static Weighing of Vehicles, such as cars, trucks, rail, aircraft, etc.

Weigh-in-Motion of Vehicles, such as cars, trucks, rail, aircraft, etc.

High Accuracy Weigh-in-Motion

Low Accuracy Weigh-in-Motion

High Speed Weigh-in-Motion

Low Speed Weigh-in-Motion

Weighing of Objects other than Vehicles

Conveyer Weighing of Goods

Weighing of People and/or Pedestrians

Weighing of Livestock

Potential clients for the disclosed WIM systems include:

Road Authorities

Transport Firms and Operators

Private Road Ventures

Toll-Road Operators/Owners

Rail Authorities and Freight Operators

Airport Authorities

Law Enforcement Authorities

Security Firms

Defence Authorities

Government Agencies

Instrument Manufacturers and Distributors

Systems Manufacturers and Distributors

Systems Integrators, Manufacturers and Distributors

Since modifications within the spirit and scope of the invention may readily be effected by persons skilled within the art, it is to be understood that this invention is not limited to the particular embodiments described by way of example hereinabove.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A weigh station for a vehicle in motion on a roadway, including;

a bore hole beneath the roadway below the surface of the roadway;

a load sensing device located in the bore hole so that the device is buried in the roadway below the surface of the roadway for measuring the load of a vehicle in motion travelling on the roadway above the device; and

processing means for receiving a signal from the load sensing device and for providing an indication of the weight of the vehicle.

2. The station of claim 1 wherein the load sensing device is located on a substrate member, the substrate member being of sufficient length to extend substantially entirely across the width of at least one lane of the roadway.

3. The station of claim 2 wherein the substrate member comprises an extrusion.

4. The station of claim 3 wherein the extrusion comprises a U-shaped channel.

5. The station of claim 3 wherein the extrusion comprises a flat beam located within a hollow conduit.

6. The station of claim 2 wherein the load sensing device comprises a plurality of electrical strain gauges supported by the substrate member.

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7. The station of claim 2 wherein the load sensing device comprises an optical fibre supported by the substrate member.

8. The station of claim 7 wherein, the optical fibre is looped on the substrate member so that a plurality of runs of the optical fibre extend across substantially the entire width of at least one lane of the roadway.

9. The station of anyone of claims 1 to 7 further including an axle detector for detecting the presence of axles of a vehicle so that an indication of the number of axles of the vehicle can be determined.

10. The station of claim 9 wherein the axle detector is arranged on the surface of the roadway and extends across substantially the entire width of at least one lane of the roadway.

11. The station of claim 9 wherein the axle detector is arranged on the substrate member together with the load sensing device.

12. The station of claim 1 wherein the bore hole is filled with a filler material which surrounds the load sensing device within the bore hole.

13. The station of claim 1 wherein the load sensing device includes a sensing fibre which extends substantially across the width of at least one lane of the roadway, a reference fibre, a coupler for coupling the sensing fibre and reference fibre, fibre sensor leads

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connected to the coupler, one of the fibre sensor leads being connected to a light source for launching light into the sensing fibre and reference fibre, and the other fibre sensor lead being connected the processing means for receiving light from the fibres and analysing the light to determine the weight of the vehicle.

14. The station of claim 13 wherein the processing means includes a light detector connected to the said other fibre sensor lead, and a third fibre sensor lead connected to the coupler, the third fibre lead being connected to a second detector so that an indication of the weight of a vehicle can be obtained by the detectors based on phase demodulation.

15. The station of claim 9 wherein the axle detector comprises a piezo-electric strip.

16. The station of claim 9 wherein the axle detector comprises a fibre optic linear modelmetric interferometer comprising a multi-mode fibre connected to a single mode fibre patch chord, the patch chord being coupled to axle detector processing means for detecting a change in property of light in the multi-mode fibre in response to a change in the load or strain experienced by the multi-mode fibre.

17. The station of claim 16 wherein a light source is provided in the axle detector for launching light into the patch chord and multi-mode fibre.

18. The station of claim 16 wherein the multi-mode fibre has a mirrored end for reflecting light from the mirrored end back through the fibre so that the detector and light

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source are arranged at one end of the multi-mode fibre and patch chord.

19. The station of claim 17 wherein the light source is arranged at one end of the patch chord and multi-mode fibre, and the detector at the other end of the multi-mode fibre.

20. The station of claim 1 wherein the load sensing device includes a single-mode sensing fibre including a Bragg grating, the single-mode fibre being connected to a single-mode fibre lead which is coupled to a coupler, the coupler having one arm connected to a light source and a further arm connected to a detector.

21. The station of any one of claims 1 to 20 wherein the load sensing device is located between 500 and 1000 mm below the surface of the roadway.

22. A method of forming a weigh station for vehicles, including the steps of;

boring a bore hole beneath the roadway;

locating a load sensing device in the bore hole so the device is beneath the surface of the roadway;

coupling the load sensing device to a processor for receiving signals from the load sensing device to enable those signals to be processed to provide an indication of the weight of a vehicle travelling on the roadway above the load sensing device.

23. The method of claim 22 wherein the step of forming the bore hole beneath the roadway comprises the step of forming an entry ditch or trench beside the roadway to

enable access of a boring device for boring the bore hole beneath the roadway.

24. The method of claim 25 wherein the entry ditch or trench is restored to original form to render invisible the weighing station beneath the roadway.

25. A method of weighing vehicles in motion on a pavement surface, including the steps of:

providing a load measuring device which respond to the load applied by the vehicle as the vehicle passes over the location of the device, the load measuring device being installed in a bore hole and under the pavement surface and extending across at least one lane of the pavement surface;

providing an axle detector in order to determine the number of axles on the vehicle;

acquiring output signals from the load measuring device and the axle detector as a vehicle passes over the load measuring device and axle detector;

analysing the signal characteristics to determine vehicle information including the weight and number of axles of the vehicle; and

recording the vehicle information in a system database or displaying or transmitting the vehicle information locally and/or remotely.

26. A method for installing a weigh in motion load sensing device, comprising the steps of:

producing a substantially horizontal bore hole across pavement lane(s) of a roadway using a boring techniques;

inserting a load sensing device into the bore hole;

filling the remaining bore hole void with filler material;

protecting sensor leads extending from the device; and

restoring the site of bore hole entry to render the site invisible to vehicle operators.

27. The method according to claim 26 further including the step of providing an axle detector for determining the number of axles associated with a vehicle the weight of which is to be determined by the load sensing device.

28. The method of claim 27 wherein the axle detector is also inserted into the bore hole.

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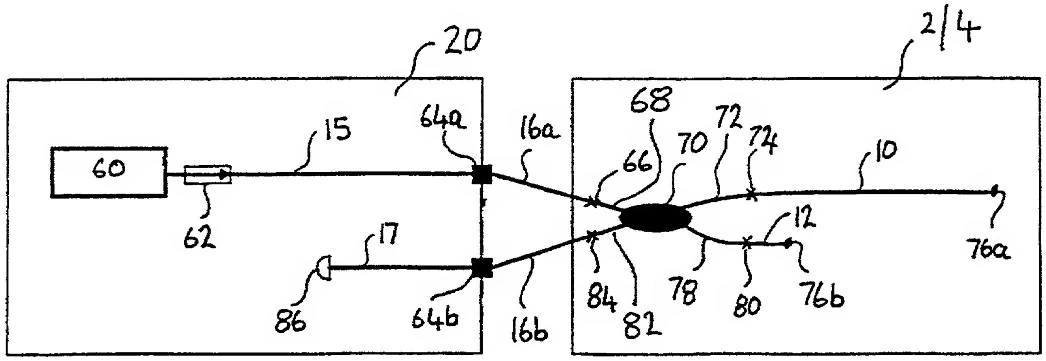
(54) Title: VEHICLE WEIGH-IN-MOTION METHOD AND SYSTEM



(57) Abstract: A method and a system of weighing a vehicle in motion which includes a load sensing device (particularly in the forms of an optic fibre cable or strain gauges) located beneath the surface of a roadway and extending across at least one lane and processing means (86) for receiving a signal from the load sensing device and for providing an indication of the vehicle weight. The load sensing device may be located on an extruded substrate member (2) that is located inside a hollow conduit. A plurality of runs of optic fibre may run across a single lane; additionally, an axle detector in the form of a piezoelectric strip or an optic fibre cable may be included in parallel. An optic fibre system may include a light source (60), a sensing fibre (10), a reference fibre (12), a coupler (70) connecting the fibres and processing means (86) for analysing the light and determining the weight of the vehicle. In accordance with one particular disclosed method of installation, an entry trench is dug beside a roadway to enable the boring of a borehole beneath the roadway, then a hollow conduit having a load sensing device supported on a substrate member (2) inside the conduit is introduced in the borehole and finally the borehole is filled with filler material.

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Figure 1

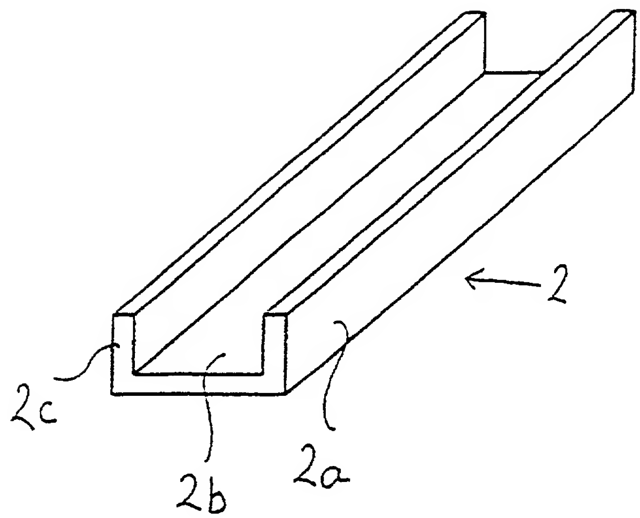


Figure 10

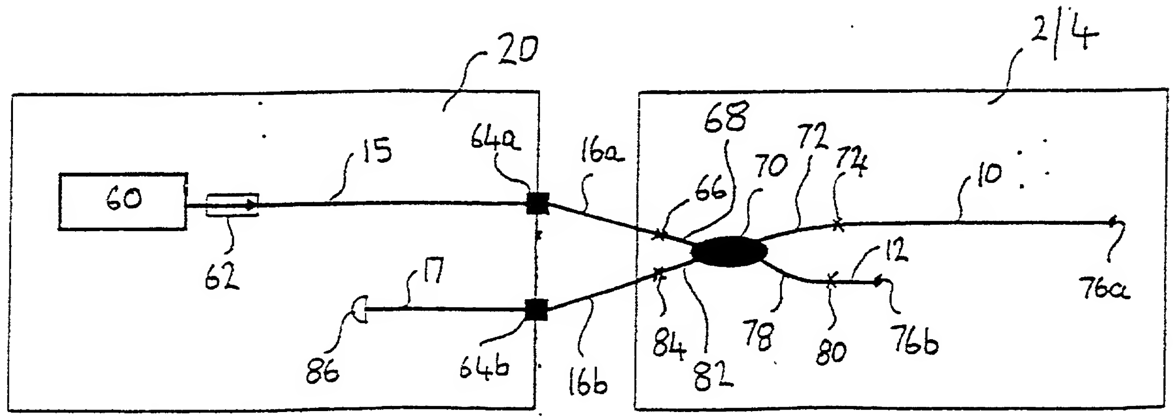


Figure 2

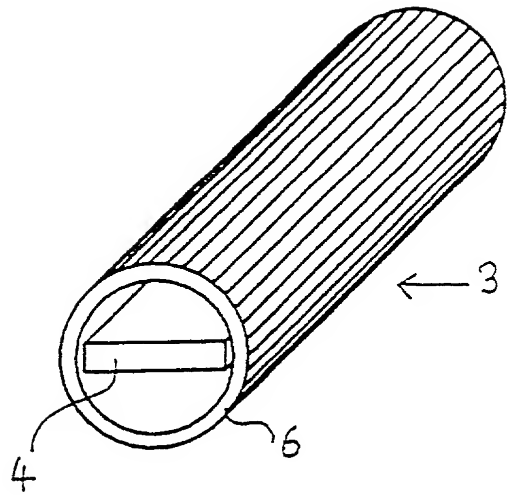


Figure 15

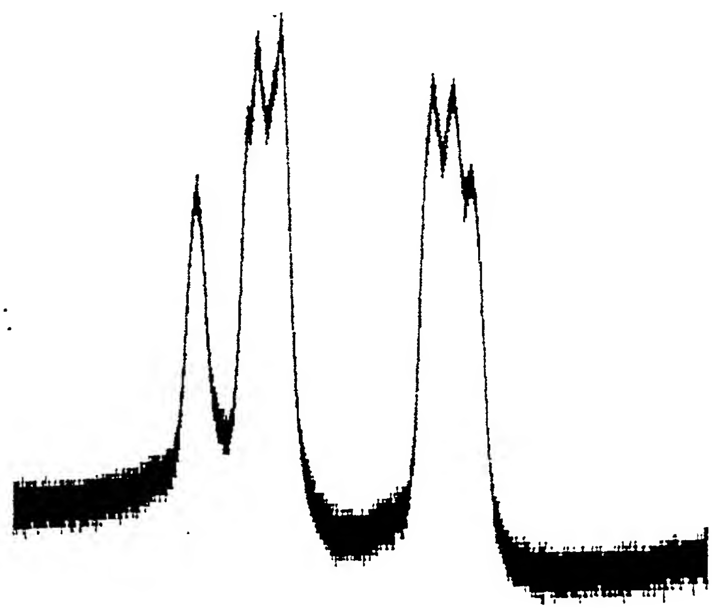


Figure 3

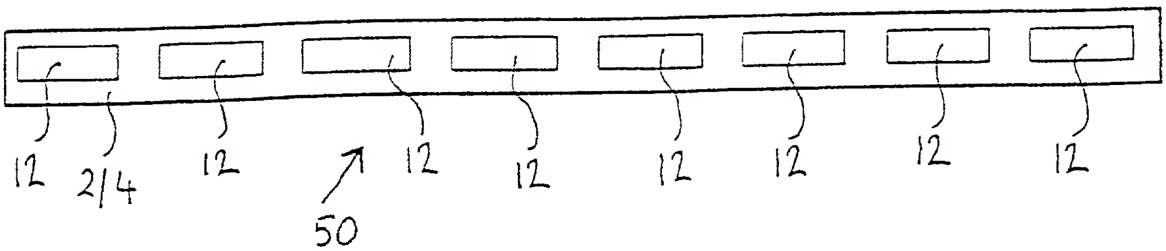


Figure 4

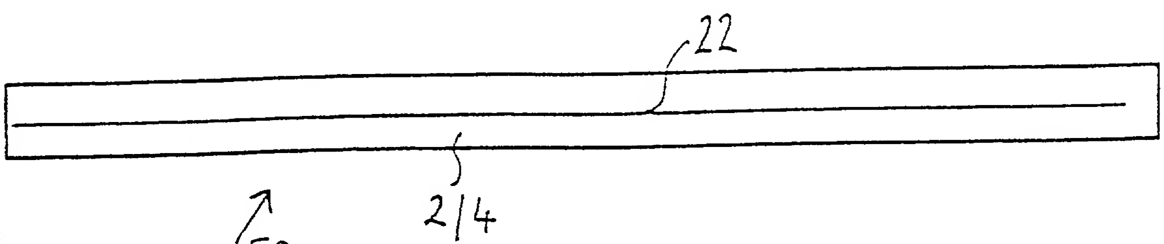


Figure 5

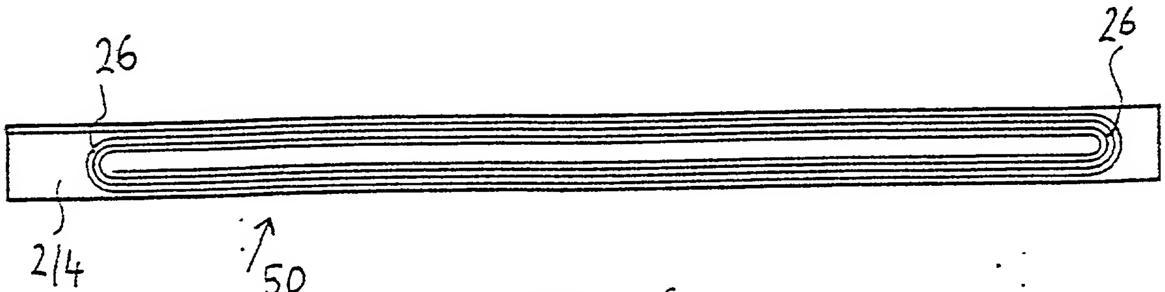


Figure 6

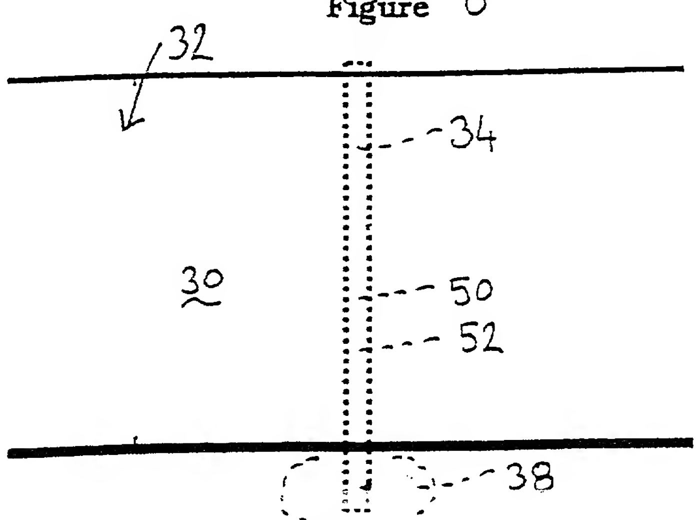


Figure 7

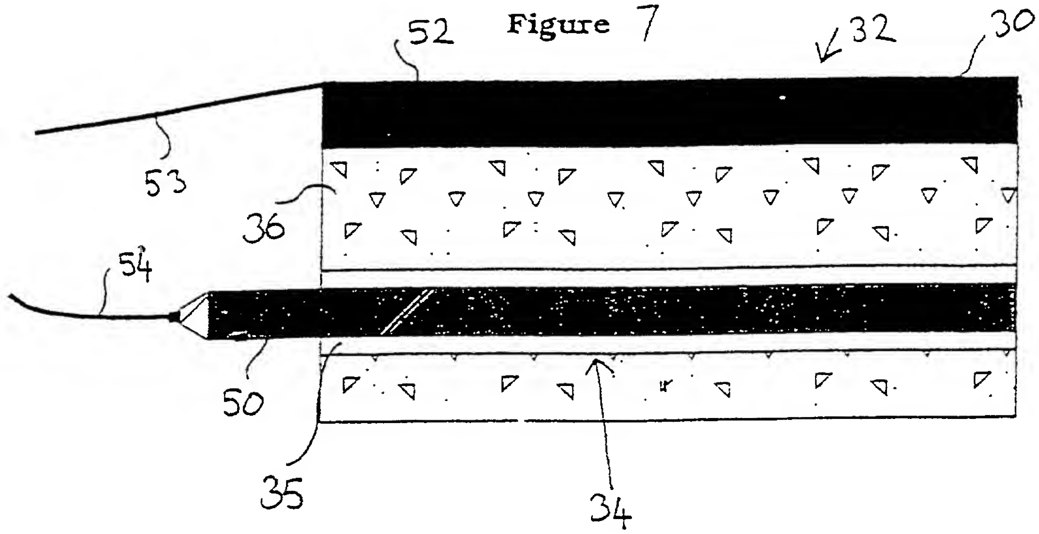


Figure 8

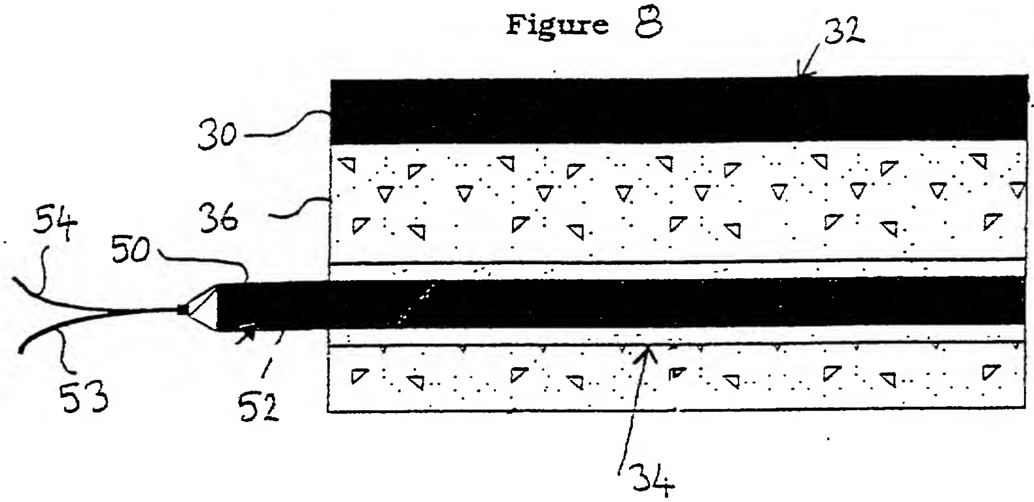


Figure 9

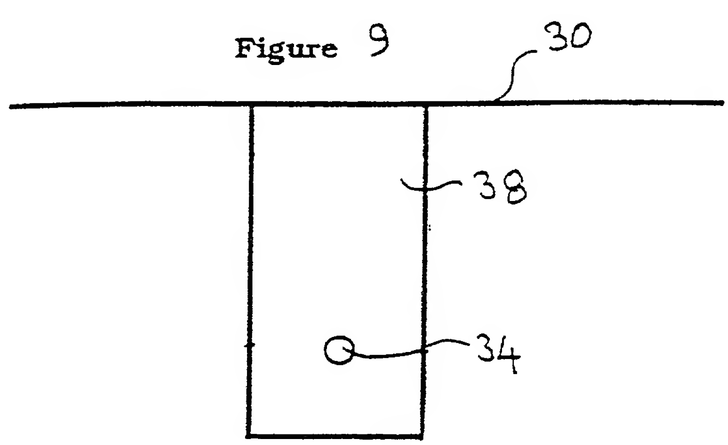


Figure 11

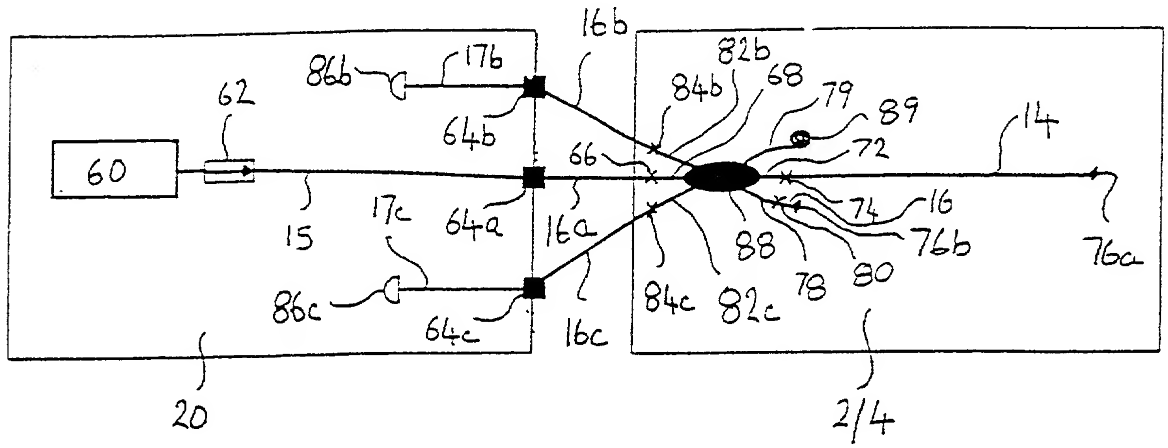


Figure 12

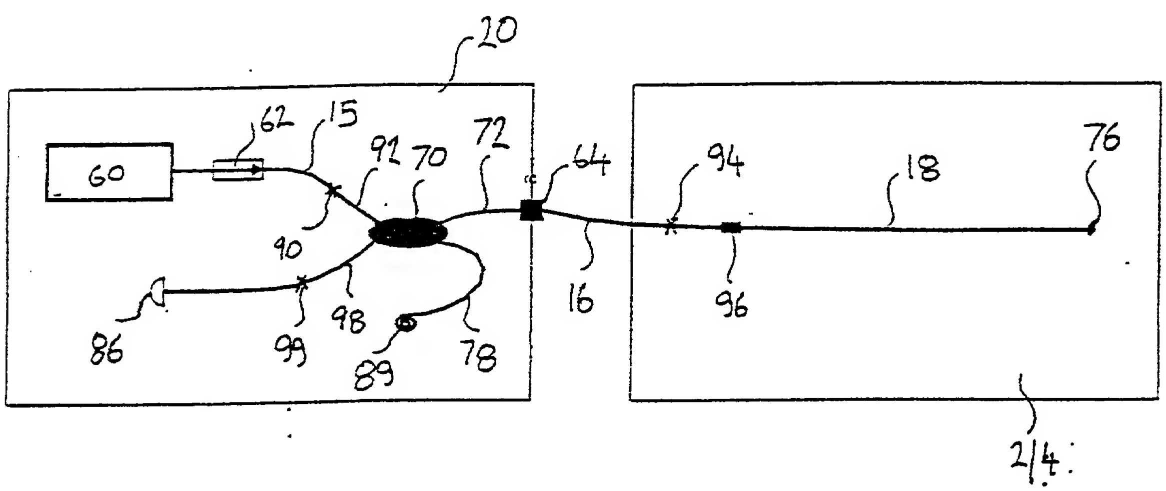
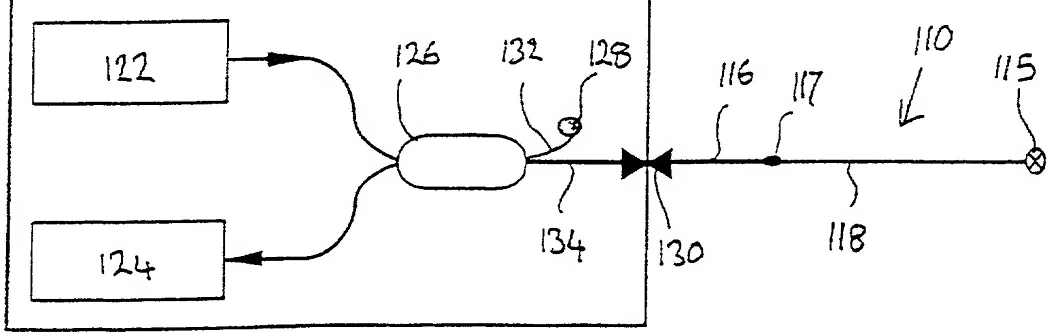


Figure 13



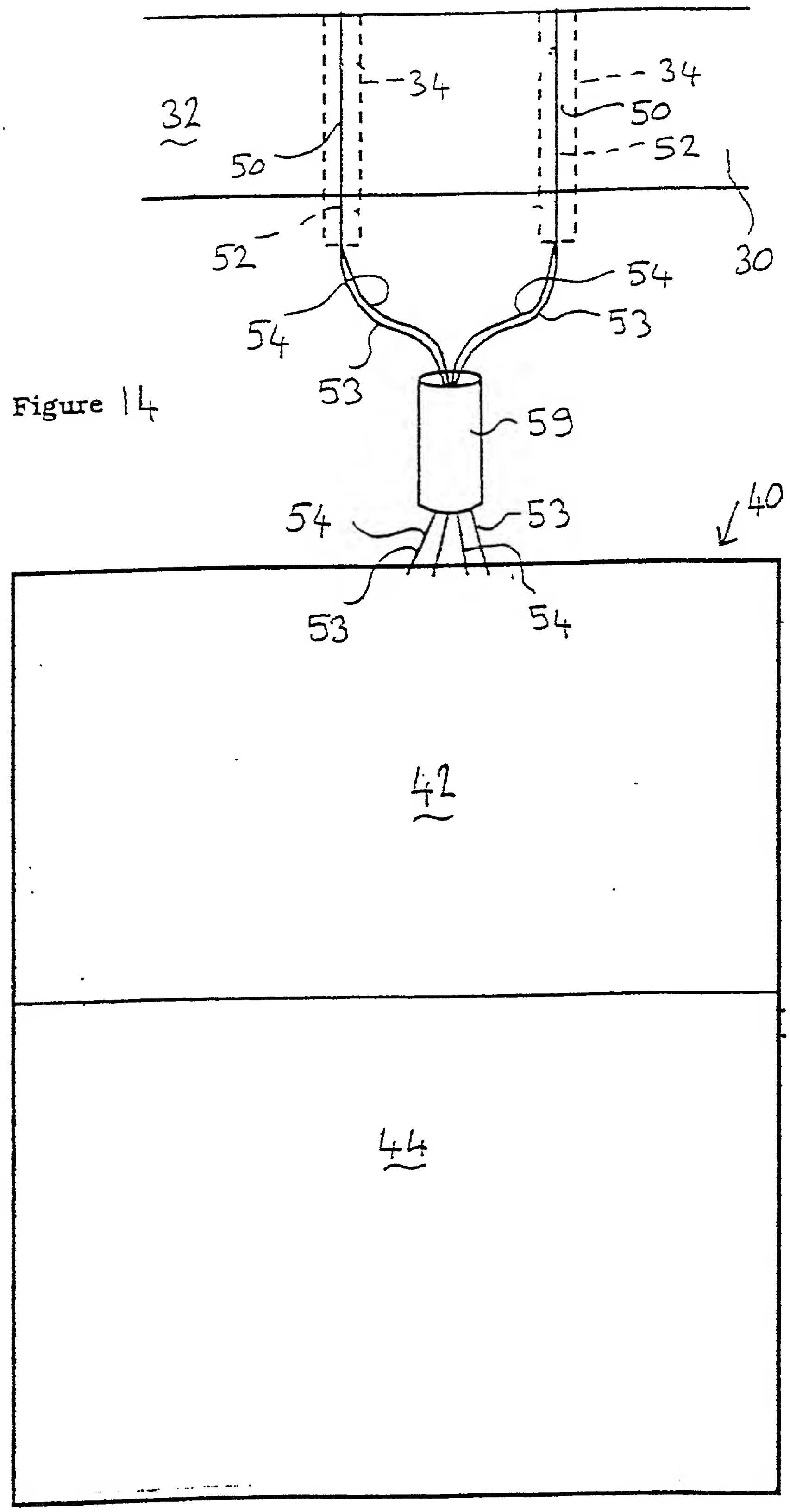


Figure 14

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

( ) Original ( ) Supplemental ( ) Substitute (X) PCT

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled "Vehicle weigh-in-motion method and system," which is described and claimed in the specification

(check one) [ ] which is attached hereto, or
[ ] which was filed on ________________, as United States Application No. ________________ and with amendments through ________________ (if applicable), or
[X] in International Application No. PCT/AU00/01053, filed 5 Sept 00 and as amended on 22 Aug 01 (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information known by me to be material to the patentability of the claims of this application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119 (a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATIONS: (ENTER BELOW IF APPLICABLE)			PRIORITY CLAIMED (MARK APPROPRIATE BOX BELOW)	
APP. NUMBER	COUNTRY	DAY/MONTH/YEAR FILED	YES	NO
PQ3357	Australia	12 October 1999	Yes	

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

APPLICATION NUMBER	FILING DATE

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose all information known by me to be material to the patentability of the claims of this application as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NO.	FILING DATE	STATUS (MARK APPROPRIATE COLUMN BELOW)		
		PATENTED	PENDING	ABANDONED

I hereby appoint the following attorneys and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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